THE INFLUENCE OF PHOSPHORUS AND SULPHUR ON THE MECHANICAL PROPERTIES OF STEEL.

IN drawing up specifications of the chemical composition of carbon steels the following five elements are invariably included: carbon, silicon, manganese, phosphorus, and sulphur. With respect to the first three it is always specified that the percentage present shall fall *within* certain limits, whereas as regards the last two only an *upper* limit is demanded. These specifications are based on the assumptions that while carbon, silicon, and manganese confer desirable properties on the iron with which they are alloyed, the character and degree of which can be regulated by the amount introduced, phosphorus and sulphur act unfavourably, and should be kept down to the lowest possible figures. They are universally regarded as embrittling agents, which must on no account be present above a certain limit in any particular case. In fact, if it were possible to reduce the percentage of these elements to nil in commercial steels, few, if any, engineers would hesitate to specify that such steels should be absolutely free from them.

The war, however, has upset a number of views which previously were regarded as well established, and in a paper presented at the autumn meeting of the Iron and Steel Institute in London entitled "The Influence of Some Elements on the Mechanical Properties of Steel" Dr. Stead has given a distinct jog to the opinion that sulphur and phosphorus are always and necessarily deleterious to the properties of the steel with which they are alloyed. The paper is one of considerable length, and deals not only with the five elements mentioned above, but also with copper and tin. It is in the nature of a stocktaking of the results reached in researches bearing on the influence of these particular constituents. Naturally carbon and the heat treatment of steel come in for the lion's share of attention, but it is only in the case of sulphur and phosphorus that Dr. Stead has arrived at conclusions which challenge generally accepted opinions, and which deserve—and on account of their far-reaching practical significance are certain to obtain—the most searching scrutiny and, indeed, criticism.

From first to last the word "shell" is never mentioned in the paper. Nevertheless it is the fact that it was the bombardment of Hartlepool, Scarborough, and Whitby in December, 1914, by the German battle-cruiser squadron which gave the impetus to Dr. Stead's investigation. Pieces of German shells were analysed by him and found to contain considerably higher percentages of sulphur and phosphorus than are permitted in British specifications of similar material. This at once raised in his mind the question whether it is really necessary to adhere to the particular percentages in vogue, and caused him to study anew the evidence upon which existing specifications have been based.

Considering phosphorus in the first instance, it would appear from the researches of Dr. Stead and d'Amico that within certain limits the effect of 0·1 per cent. of this element is comparable with that of carbon, as the following table shows:—

	The effect of 0·1 per cent. of carbon.	The effect of 0·1 per cent. of phosphorus	
		Stead	d'Amico.
	Tons per sq. in.	Tons per sq. in.	Tons per sq. in.
Yield point, raised...	1·78	2·5	2·3
Maximum stress, raised ...	4·18	2·4	4·1
	Per cent.	Per cent.	Per cent.
Elongation, reduced	4·35	0·7	1·36
Reduction of area, reduced ...	7·40	1·5	3·8

It will be observed that carbon causes a proportionately greater reduction of ductility than phosphorus, and, judged by this test, is a more powerful embrittling agent. Furthermore, it appears from Dr. Stead's experiments that a steel containing 0·30 per cent. of carbon and 0·50 per cent. of phosphorus resisted long-continued rotary stresses better than a steel with the same carbon percentage and only 0·04 per cent. of phosphorus. These steels were in the forged condition, and their structure was "very fine." Dr. Stead also claims that "there is no reliable record showing that sound steel rails containing from 0·07 to 0·09 per cent. of phosphorus break up on the track more frequently than those containing less phosphorus," and that "phosphoretic rails undoubtedly resist wear better than the same rails with less of that element present." He recalls the fact that previous to the use of steel rails, when iron was employed, it was customary "to have iron very rich in phosphorus in the heads of the rails, for it was recognised that the phosphoretic iron wore better than the purer material." His general conclusion is:—"When judging the properties of steel note should be made of the fact that in many cases when carbon is rather low phosphorus may be an advantage, for it has similar influence to carbon which it replaces. Phosphorus has got a bad name, like many other elements, but, far from always being an enemy, is often a friend."

As regards the influence of phosphorus on wrought iron, Dr. Stead affirms that the best Yorkshire and Staffordshire irons contain between 0·10 and 0·15 per cent. of this element, and that for structural purposes they are superior to the best Swedish irons, which contain a smaller amount. The elastic limit, yield point, and ultimate stress are all raised, and the irons weld more easily. The danger limit is put by him at from 0·4 to 0·5 per cent., in which range brittleness develops and also a tendency to very coarse crystallisation if such iron is heated to high temperatures.

Ever since the pioneering work of Brinell, Wahlberg, and Arnold, it has been recognised that provided rather more than sufficient manganese is present to form manganese sulphide with the sulphur in steel, no red-shortness occurs. Arnold and Waterhouse showed this in 1903 for a steel of the following composition:—

Carbon	Silicon	Manganese	Sulphur	Phosphorus
0·460	0·369	1·060	0·560	0·055

which rolled perfectly, and was found to be ductile both in the tensile and impact tests. They also proved conclusively that while sulphide of manganese in steel is not deleterious, sulphide of iron

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is very deadly in its effect, and showed why this was so. Nevertheless sulphur had got a bad name in the early days of steel-making, chiefly owing to the fact that it was impossible to introduce sufficient manganese without raising carbon unduly, the only material available being German spiegeleisen. When, however, the Ebbw Vale Steel Company was able to produce an alloy containing a much higher percentage of manganese this difficulty vanished. In spite of this, sulphur's bad name has stuck, and even to-day, according to Dr. Stead, steel rails are rejected which pass all the specified mechanical tests because the percentage of sulphur exceeds an arbitrary limit. He states that steel high in sulphur resembles wrought iron, and is, like that material, more or less fibrous. Perhaps his most interesting—certainly his most challenging—statement with regard to sulphur is the following:—"It is a fact that steel called free-cutting fibrous steel is being imported and used in England to-day, and the peculiar properties referred to are due to the deliberate introduction of sulphur into the steel. Such material contains about 0·15 per cent. sulphur. Sulphur, then, may be regarded as a friend when it is used intelligently, and not invariably as the enemy it is represented to be." A point, however, in connection with the question of the possible use of high-sulphur steels that requires careful investigation is whether such materials would be more liable to atmospheric corrosion than low-sulphur steels.

The issues raised by Dr. Stead with regard to the influence of phosphorus and sulphur in steel are of the utmost importance in their relation to the manufacture of steel in this country, both during and after the war. In the discussion on his paper he stated that at the beginning of the war sulphur was restricted to 0·04 per cent. in all shells, and that it was alleged that these would be liable to fail if the proportion was raised to 0·06 per cent., but that, thanks to Sir Robert Hadfield, the limit had been raised to the higher figure, and shells did not fail more in the gun than formerly. This raising of the limit has made it possible to increase the output of shell steel. Can the limit be raised still further? That is the question. The case that Dr. Stead has made out for reconsidering the particular limits imposed on sulphur and phosphorus in ordnance steel specifications is very strong. Chemical analysis is introduced into steel specifications in order to aid in securing that the requisite properties—chemical, physical, and mechanical—are obtained. If steels possessing those properties can be prepared which do not come within the chemical specification the latter requires revision. In such matters chemical analysis is the servant. It should not be allowed to become the master. By all means let the authorities concerned subject Dr. Stead's conclusions to the severest criticism, and test them experimentally in the most thorough way. It ought to be done without delay. He has raised the question in the interests of the nation. It is earnestly to be hoped that the authorities will approach it in the same way.

H. C. H. CARPENTER.

WORK OF THE GOVERNMENT LABORATORY.

FROM the recently issued report of the Government Chemist,[1] it appears that 239,706 samples were analysed at the Government Laboratory during the course of the year 1915–16. This is an increase of some 9300 samples compared with the previous year, and of about 5000 compared with the year 1913–14, before the outbreak of war. The samples comprised a large variety of articles.

The greater part of the work of the department is carried out in the main laboratory at Clement's Inn Passage and in the branch laboratory at the Custom House. There are, however, eighteen chemical stations in different parts of the United Kingdom at which revenue samples alone are examined; these were responsible for the testing of an additional 144,186 samples of dutiable goods during the period in question. At one time the laboratory was devoted solely to revenue work. It was, in fact, established (in the year 1843) with the single object of checking the adulteration of tobacco. From time to time, however, State departments other than those concerned with fiscal questions have found that they required assistance in the form of analytical work or other matters involving chemical knowledge, and the services of the laboratory officials have been requisitioned to meet these demands, as well as to carry out the provisions of certain statutes relating to the adulteration of foods, drugs, and other articles. Thus from a purely revenue establishment the laboratory has in process of time become a general State laboratory for purposes lying mainly in the domain of analytical chemistry, but including also advisory work arising in connection with a considerable variety of chemical questions.

With this extension of scope the status of the laboratory has naturally undergone alteration. Some time ago the department was reconstituted, and it may be of interest to indicate its present standing. Whereas in the early stages of its career the laboratory was a small scientific branch placed under the control of a large fiscal department, it has now been made a separate and independent establishment supported by funds provided under a separate Vote in Parliament—namely, that for the "Department of the Government Chemist." The head is a scientific man responsible directly to Parliament for the expenditure of moneys voted. Thus the laboratory is now under a single administrative control, and, subject to general oversight by the Treasury, enjoys the privilege of independent action.

This alteration of status is a matter of some importance as indicating a sympathetic and sagacious policy for which the authorities deserve due credit. No doubt it might be said that the former arrangement had its counterpart in such instances as the Greenwich Observatory (placed under the Admiralty) or the Geological Survey (under the Board of Education). These, however, are not quite analogous cases. It was a question

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[1] Report upon the Work of the Government Laboratory. Cd. 8394. (London: Wyman and Sons, Ltd., 1916.) Price 2½d.

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